Nd:YAG LASER INDUCED
NONLINEAR SELECTIVE REFLECTION
BY A CHOLESTERIC LIQUID-CRYSTAL MIRROR

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We have observed lowering reflectivity (from 85\% up to 50–70\%) of a cholesteric liquid-crystal (CLC) mirror under the nonlinear action of circular-polarized laser radiation. The possibility is considered of nonthermal but light field-induced helical pitch dilation and untwisting. It is the first experiment (a special laser operation was chosen, so that the changes of pitch could be accumulated), where such strong changes of reflectivity can be explained by athermal effects. We also observed defocusing of the reflected beam with a near Gaussian profile and changing of the CLC mirror curvature, but thermal effects are more probable in these experiments.

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1. Introduction

Light-induced pitch dilation of the CLC helix\textsuperscript{[1]} under the conditions of selective Bragg reflection of circular-polarized light with changing of CLC reflectivity was widely discussed theoretically, e.g. in [2,3]. The following mechanisms have been considered: (i) action of strong electromagnetic field of an intense light wave [2,3] and (ii) heating of the CLC by photoabsorption [3]. As to experimental results, only thermal changes of pitch were observed in [4,5] where some absorbing substances were added to a CLC liquid. The authors of [6] using short (15 ns) pulses did not detect the strong light field effect predicted in [2] at the power density even 8 times higher than estimated value (about 1 MW cm\textsuperscript{-2}). In the set of papers [7–14] the changes in curvature of CLC mirrors under cw laser irradiation were explained as a result of pitch dilation in the field of light wave. The authors of cited papers considered thermal effects to be excluded by careful cleaning of the CLC in the clean-room conditions. It should be mentioned that the strong lowering of reflectivity (as in our experiments) was not observed in [7–14].

In the present paper we observe for the first time the strong changes in reflectivity of CLC mirror that can be explained as a result of athermal but light-induced helical pitch dilation up to untwisting under the conditions of selective Bragg reflection. We also observe changes in the CLC mirror curvature (defocusing) as in [7–14], but we believe the changes of pitch by heating to be more probable in this case.

2. CLC mirror characterization

The CLC mirror consisted of a blend of nematic liquid crystal E7 and chiral additive CB15 (EM Chemicals) [7–14] and was prepared by the authors of [15]. The planar alignment was provided by coating both inner surfaces by
polyvinyl alcohol (PVA) and buffing one of them for strong surface anchoring [11]. The average refractive index of the mixture was $n_{av} = 1.557$, and temperature could shift a selective reflection curve from 0.3 to 1.4 nm-deg$^{-1}$ in similar mixtures [10]. The LC mixture used in our experiments was cleaned by authors [7–14] in the conditions of clean room, but the CLC mirror was made in the ordinary laboratory conditions. The CLC thickness was 20 μm. Figure 1 shows a transmission profile of the CLC mirror at different wavelength $\lambda$: (a) for circular-polarized light and (b) for unpolarized light. The reflectivity in maximum of the Fig. 1a curve is about 95% at $\lambda = 1.052 \mu$m. In our experiments reflectivity of the CLC mirror was approximately 85% at the laser wavelength $\lambda = 1.064 \mu$m.

3. Experimental

3.1. Experimental setup

Figure 2 shows the experimental scheme. A commercial Nd:YAG laser LTI-701 was used for this work. The laser could operate in two regimes: (i) continuous-wave and (ii) pulsed one (500 ns pulses with 4.5-kHz repetition rate by using an acousto-optical switch). In both operations the average power in single-mode lasing was 0.3–0.5 W. The incident and transmitted Nd:YAG powers were detected by a calibrated photodiode and a power meter. The beam patterns were recorded by a CID video camera with computer processing. Pulse duration and repetition rate were measured by an avalanche pho-

![Figure 2](image-url)

**Figure 2.** Experimental setup: $L$, laser; $F$, glass filters; $QP$, quartz polarizer; $PD$, photodiode; $APD(PhM)$, avalanche photodiode (photomultiplier); $\lambda/4$, quarter-wave plate; $CLC$, CLC mirror; $CID$, video camera; $l$, lens; and $PM$, power meter.
todiode and a photomultiplier. The output laser beam passed through the system of glass filters, a quartz polarizer, a $\lambda/4$ plate for circular polarization, and a CLC cell. To increase the incident power density the lens with a focal length of about 5 cm was placed in front of the CLC mirror in some experiments.

3.2. Nonlinear bleaching of the CLC mirror

CLC mirror in a free space (irradiated by a focused laser beam). We detected the increase in transmission of the CLC mirror from 15% up to 30–50% (within accuracy of 5%) at peak power density $\approx 10^6$ W·cm$^{-2}$ by focusing the laser beam with the lens. The bleaching appeared after 30 s–1 min irradiation (Fig. 3). We observed one, two or three steps at the bleaching. We explain this delay by accumulation of changes of the CLC pitch in a high-repetition rate laser field [21, 22]. (The laser pulse was much shorter than the time of helix untwisting ($\approx 10^{-3}$ s), which is why the bleaching had not been observed in [6].) We consider this effect as athermal, but as the result of the strong field action, because of a dependence on the peak-power density rather than on an average one. When we changed the operation of laser to cw lasing, this effect was not observed even at the doubled average power density ($\approx 1$ W) than in the case of 500-ns 4.5-kHz lasing.

CLC mirror in a laser resonator. These results have also been confirmed when we used

![Figure 3. Dependence of the CLC mirror transmission on time of bleaching. Solid, dotted, and dashed lines correspond to one-, two-, and three-step bleaching.](image)

Figure 4. CW laser output power versus lamp current: (•) laser with a conventional dielectric output mirror and (×) laser with the CLC output mirror.

the CLC cell as an output mirror of resonator in the Nd:YAG laser. The cw lasing was very stable. Figure 4 plots the dependence of output power versus lamp current in the cases of a CLC output coupler (crosses) and a conventional dielectric output coupler (dots) for cw laser operation with output power higher than 1 W. In the case of short-pulse lasing, it disappeared in 30 s–1 min after switching on the 500-ns 4.5-kHz operation because of nonlinear bleaching of the CLC mirror. We also observed steps in lowering of output power as in the free-space bleaching of the mirror.

It should be noted that in addition to [7–14], some authors [16–20] also used the CLC mirrors in laser resonators, but oscillation parameters and reflectivity of the mirrors did not allow them to observe such strong changes of reflectivity as in our experiment.
Figure 5. Cross section (at the distance of 2 m) of the beam reflected by the CLC mirror (a) and the dielectric mirror (b).

3.3. Nonlinear defocusing of the laser beam in a free space

We also observed defocusing of an unfocused single-mode laser beam with the Gaussian profile, reflected from the CLC mirror at an average power density \( \geq 10^4 \text{W} \cdot \text{cm}^{-2} \). Figure 5a shows cross section of the beam reflected by the mirror at a distance of 2 m. For comparison, the beam cross section at the same distance in the case of a conventional dielectric mirror is shown at Fig. 5b. Figure 6 represents a spatial profile of the beam for the two cases (curves 1 and 2) along the diameter AA. All the data (Figs. 5 and 6) were taken by using a video camera CID Technologies 2220A with the 270H×264V CID 33 imager, having square pixels 28×28 \( \mu \text{m} \), and an Image Nation Cortex-1 video frame grabber with processing on a PC.

To evaluate the optical strength of nonlinear mirror, we used glass negative lenses at the same position as the CLC mirror. The 80–100-cm focal length lenses gave the same defocusing as the nonlinear mirror. We considered this effect as thermal because there was no strong difference in cw and 500-ns 4.5-kHz operations. It should be noted that the high quality beam was reflected only by the side of the CLC mirror with strong surface anchoring, while the beam reflected from another, nontreated side had a worse quality (Fig. 7).

Figure 6. Reflected beam intensity \( I \) profiles versus distance \( a \) along the line AA (at 2 m): (1) CLC mirror \((e^{-1}-\text{diameter} \ 1.9 \text{mm} \quad \text{and} \quad e^{-2}-\text{diameter} \ 2.52 \text{mm})\) and (2) dielectric mirror \((e^{-1}-\text{diameter} \ 1.4 \text{mm} \quad \text{and} \quad e^{-2}-\text{diameter} \ 1.95 \text{mm})\).

Figure 7. Cross section of the beam reflected from the side of CLC mirror with bad anchoring (at the distance of 2 m).
4. Conclusions

1. We have shown experimentally for the first time the possibility of strong changes in a pitch of the cholesteric liquid crystal with violated conditions of Bragg reflection in the field of a light wave (not only in static fields). For observing this effect, we chose the laser-pulsed operation with high repetition rate of 4.5 kHz. That is why we observed nonlinear bleaching of the CLC mirror at the pulse duration of 500 ns, which was much shorter than the time of helix untwisting ($10^{-3}$s) by accumulation of the pitch changes. The effect was observed both for the free-space irradiation (focusing the laser beam into the CLC cell), and in a laser resonator where the CLC cell was used as an output mirror.

We consider this effect as a result of athermal action of the strong field, because of its dependence on the peak power density and not on the average one. However, to exclude totally the thermal effects, further experiments are desirable.

2. We also observed nonlinear defocusing of the Gaussian laser beam reflected from the CLC mirror and changing of the mirror curvature. We consider these effects as thermal because there was no strong difference in cw and 500-ns 4.5-kHz laser operations.

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References